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Physiologic Field Evaluation of Hazardous Materials Protective Ensembles

Federal Emergency Management Agency
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PHYSIOLOGIC FIELD EVALUATION OF HAZARDOUS MATERIALS PROTECTIVE ENSEMBLES

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PREFACE

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<u>Disclaimer:</u> Mention of brand names of various protective garments does not constitute endorsement by FEMA, USFA or the author. Brand names are mentioned for purposes of identification, to stimulate product improvement and to ultimately increase the safety for members of the fire service wearing HAZMAT protective clothing.

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ABSTRACT:

Five experienced hazardous material (HAZMAT) fire fighters participated in field tests at each of four cities to evaluate three HAZMAT protective ensembles. The climatic conditions for these field studies were hot/dry (102° to 108°F), hot/wet (86° to 63°F), comfortable (70° to 81°F) and cold (42° to 45°F. Each fire fighter served as his own control and wore a specific HAZMAT protective ensemble once a day for three days. Each test Involved an operationally relevant 45 min work session during a total test duration of 55 mins. Rectal temperatures (TR), heart rates (HR), blood pressures, respiration rates, clothed weights and climatic parameters were recorded before and after each test. Test results show average TR, HR and sweat losses increased to 101.4°F, 208 beats /min and 3.5 Ibs respectively during the hot/dry, hot/wet exposures. The wet bulb globe temperature (WBGT) levels for the hot/dry conditions exceeded the NIOSH recommended limiting criteria and was marginal for the hot/wet tests. Physiologic parameters measured during comfortable and cold conditions were similar to each other and lower than those measured during the hot/dry or hot/wet conditions. Differences in suit design were clearly reflected in the measured physiologic parameters and the effort required to perform work. Suggested suit modifications are discussed to reduce clothing encumberance and enhance work efficiency.

KEY WORDS: HAZMAT protective clothing, fire fighters' clothing

INTRODUCTION

With increasing frequency during the past twenty years, the fire service has been called upon to respond to and alleviate toxic chemical spills, fumes and fires involving toxic chemicals. These incidents have become more critical over the past ten years as public awareness has increased to the potential seriousness of the problem. This increased responsibility for fire service personnel has thrust them into a new area that requires different protective clothing than the standard “turnout” clothing. It has also made necessary new procedures for handling these incidents. Although federal and professional guidelines for handling hazardous material (HAZMAT) incidents are being developed, few studies have addressed protective clothing requirements (Schwope et al, 1983; Unknown author, 1984; 1985). The obvious problem of chemical permeation through protective clothing has been the first to be addressed. Based upon these chemical data and other criteria, Noll (1984) and others developed classes of HAZMAT incidents that require different levels of clothing protection. But, the physiologic impact of wearing the impermeable HAZMAT clothing during operationally relevant conditions has seldom been addressed by the fire service. However, data are available from studies describing the physiologic response of exercising people exposed to temperature extremes dressed in impermeable clothing. The results of some of these studies are described below.

Impermeable clothing (chemical resistant) can be defined as clothing which prevents transfer of water and water vapor. Because these materials block water vapor transfer in hot weather, evaporative cooling of body sweat is reduced. Since evaporative cooling is the major physiological protection against overheating, impermeable clothing such as chemical resistant clothing can present a serious limitation to work In high temperatures. In an early study, Craig (1950) exposed exercising men, who were completely covered in an impermeable suit, to a temperature of 80°F. These subjects had a physiological tolerance limit of approximately 30 minutes. In another study, Darling, et al, (1943) studied a large number of men marching at three miles per hour white clothed In decontamination suits. The air temperatures ranged from 70° to 84°F. The tolerance time at 70°F was found to be about 100 minutes. This tolerance time steadily decreased as the temperature increased until at 84°F their tolerance time was only 25 minutes. Griffin, et al (1944) found that subjects dressed In heavy insulation (4 clo) and an exposure suit (impermeable) collapsed in 90 minutes at temperatures of 90°F. Without the exposure suit, collapse was delayed until 150 minutes. In another series of tests using heavy clothing (3.3 clo), Hall (1952) found that putting a light impermeable exposure suit over the clothing doubled the sweating rate and resulted in high skin temperatures. In a report by Robinson, et al (1945), a comparison was made among several types of vapor permeable and impermeable exposure suits. Test temperatures were 80 and 100°F with varying humidities and the men were either exercising constantly or intermittently. Discomfort was produced wearing all the suits with the criteria being a high skin temperture (95°F or above) and unusual moisture retention in the clothing due to the profuse sweating of the subjects. In one of the few relevant field studies, Smolander et al, (1985), determined the HR, TR and metabolic levels of fire fighters working for 37 min in a gas protective suit during cold conditions (36°F). Their findings showed a HR increase up to 148 beats/min, TR rise of 1.5°F and sweat loss of 0.66 Ibs.

In a report by White and Hodous (1987), subjects wearing chemical protective clothing exercised on a treadmill at various work levels in a thermally neutral environment (dry bulb 73°F, wet bulb 63°F). Their results showed that even at low work intensity (4 METS) tolerance time was limited to 73 mins. Tolerance time was defined as 90% of maximal HR, a TR of 102.2°F or the subject's inability to proceed. At high work levels (7.7 METS), tolerance time working in this clothing was 13 mins. One MET is defined as a metabolic rate of 50 Cal/m2/hr which is the ordinary metabolism of a person seated doing a sedentary task. Eley (1987) conducted a study with exercising subjects wearing the Challenge suit and found that at ambient temperatures of 89°F, HRs rose 40 beats/min over control values. During the forty min test exposure, the body core temperatures rose as high as 100.6°F.

With the tolerance time variously defined in the lower ambient temperature ranges (70° to 90°F) and nonexistent at the higher temperatures (100° to 160°F), it is Important to conduct field studies with HAZMAT clothing to quantify the physiologic responses of the fire fighter. This information can then be used to assess the degree of physiologic strain imposed on the fire fighter by his clothing and his work. Clothlng design also influences physiologic responses by affecting the level of work involved in performing specific tasks.

METHODS

A total of twenty experienced fire service HAZMAT trained personnel In designated Fire

Departments across the country participated in this study. These test volunteers were in good physical condition. Field tests were conducted with five fire fighters at four separate geographical locations. The cities that participated in this study were: Phoenix, AZ (hot/dry); Beaumont, TX, (hot/wet); Memphis, TN, (comfortable) and New York City, NY (cold). The climatic conditions for these four tests were cold (42° to 45°F,) comfortable conditions (70° to 81°F), hot/dry (102° to 108°F), and hot/wet (86° to 93°F).

Each fire fighter served as his own control and wore a specific HAZMAT protective ensemble once a day on three separate days. The type of HAZMAT suit worn on any given day was randomized as much as possible with respect to time of day and which of the three test days it was worn. Each test involved one work session (Table 1). Three different level A HAZMAT clothing ensembles *were* tested: the Challenge (CHAL) prototype furnished by the U.S. Coast Guard and two commercial ensembles (MSA Chempruf II (MSA) and Trellechem Super Extra (TREL). Additional tests Involved the Sta-Safe (STASAF) and Sijal (SIJAL) suits which were tested by only one fire fighter. The Sijal suit is considered a level B suit with the self contained breathlng apparatus (SCBA) worn outside the clothing. The STASAF suit is a level A or totally encapsulated suit. The purpose of evaluating the STASAF suit was to determine the physiologic impact of using a 250 ft. tethered airline versus a non-tethered airline source to the SCBA.

The experimental procedure was to weigh the person nude and instrument them with a rectal temperature (TR) probe inserted 4 In. into the rectum. Dressing was accomplished In a cool environment to preclude sweating before the test started. After each Individual clothing item was weighed dry, the totally clothed subject was weighed. Weights were recorded either on a HeathKit digi scale, Model CD 1186 with an accuracy of 0.09 lb or on a FWC digital scale, Model DWM IV with an accuracy of 0.02 lbs. Each fire fighter was dressed In his undergarments, station uniform and street shoes. In addition, they wore a HAZMAT protective ensemble, and an MSA 4500 SCBA. The fire fighter used his own personal mask. The total average weight of the entire protective equipment system was approximately 50 lbs. While carrying the water filled buckets, the combined weight carried by the fire fighter was 100 Ibs. Rectal Temperature, Heart Rate, Blood Pressure (BP), and Respiration Rates (RR) were recorded before and after each test. Blood pressure was recorded either with a Norelco Digital unit, Model HC3030, or manually (blood pressure cuff) by an experienced paramedic fire fighter. Heart rates were obtained manually or with a 1-2-3 Heart Rate monitor. Respiration rates were counted manually. Two inside HAZMAT garment surface temperatures were measured. One site was immediately above the visor while the second was immediately below the visor. Rectal and suit temperatures were measured with a YSI Model 46 TU telethermometer, using series 400 thermistor probes. The ambient temperature (TA), ambient humidity (RH), globe temperature (GT) and wet bulb-globe temperatures (WBGT) and wind velocity (WV) was recorded with a Wibget Heat Stress Monitor Model RSS-212 to describe the physical environment. The fire fighter then proceeded with the prescribed work task.

A realistic HAZMAT work task was selected and used in each test city. The duration of the entire test was 55 mins with only 45 min involving active exercise. The event/time frame below was followed by each of the fifteen subjects in each test city.

TABLE 1. Work/Time Sequence

TIME FRAME	EVENTS
0 to 5 mins	• Walking around outside in the sun to simulate prior body heating prior to entering incident site.
5 to 10 mins	•
10 to 20 mins	• Suit up in HAZMAT cbthing. On air at time 20 min.
20 to 30 mins	• Walk 500 ft. to the spill area.
30 to 50 mins	• Walk back 500 ft. and carry two pails, each filled with 25 Ibs of water. Repeat this task 3 times walking between the barrels and the starting point. This activity simulates construction of a moat with absorbent material around a acid spill. Taking the sealing ring off overpack.
50 to 55 mins	• Walk back 500 ft. to the decontamination site.

Physiologic tolerance criteria for this study was a TR of 102.2°F or a HR of 180 for 3 minutes. Termination of any test was mandatory upon the request of: 1) the fire fighter; 2) the fire fighter's site supervisor; or, 3) upon the discretion of the test monitor based on subjective or the above physiologic criteria. For each test a paramedic team stood by with an ambulance in the event of a medical emergency.

RESULTS

The physiologic responses of the fire fighters clearly show the impact of the environmental parameters. Figures 1 A and 1 B show the effect of the four climatic conditions on heat rate. All

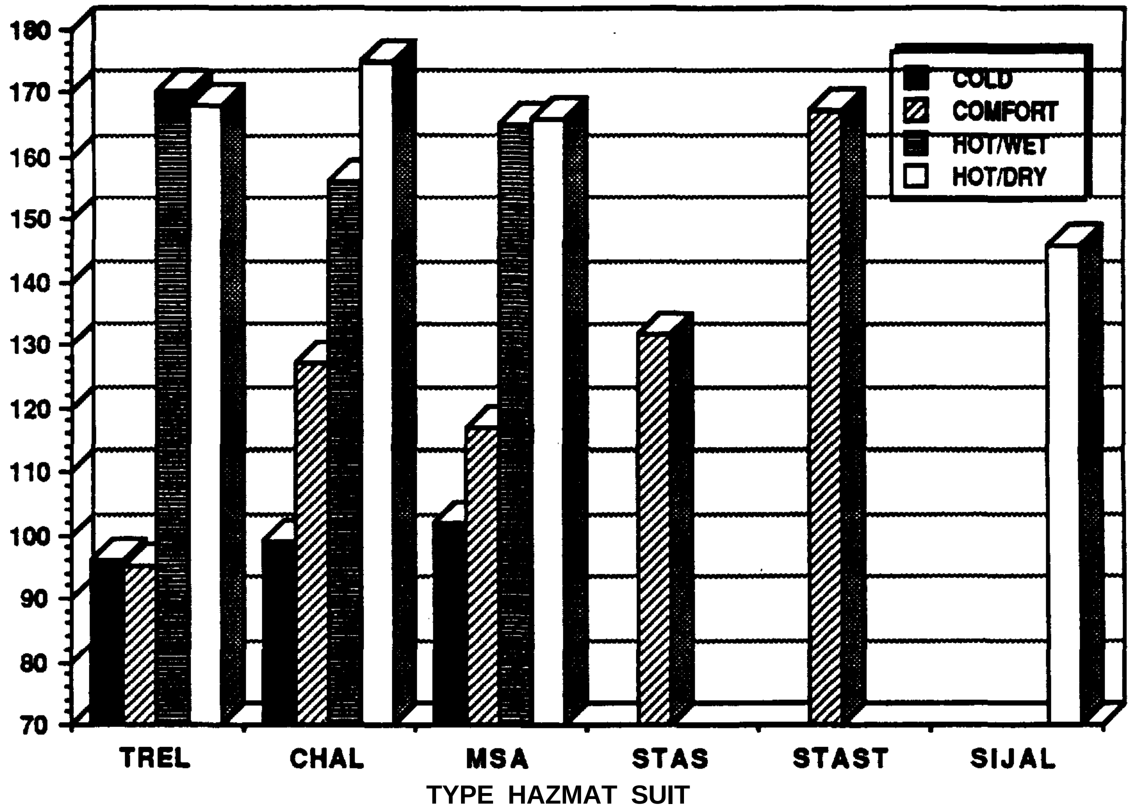

FIG. 1A. EFFECT OF WORK AND CLIMATIC CONDITIONS ON ABSOLUTE HEART RATE.

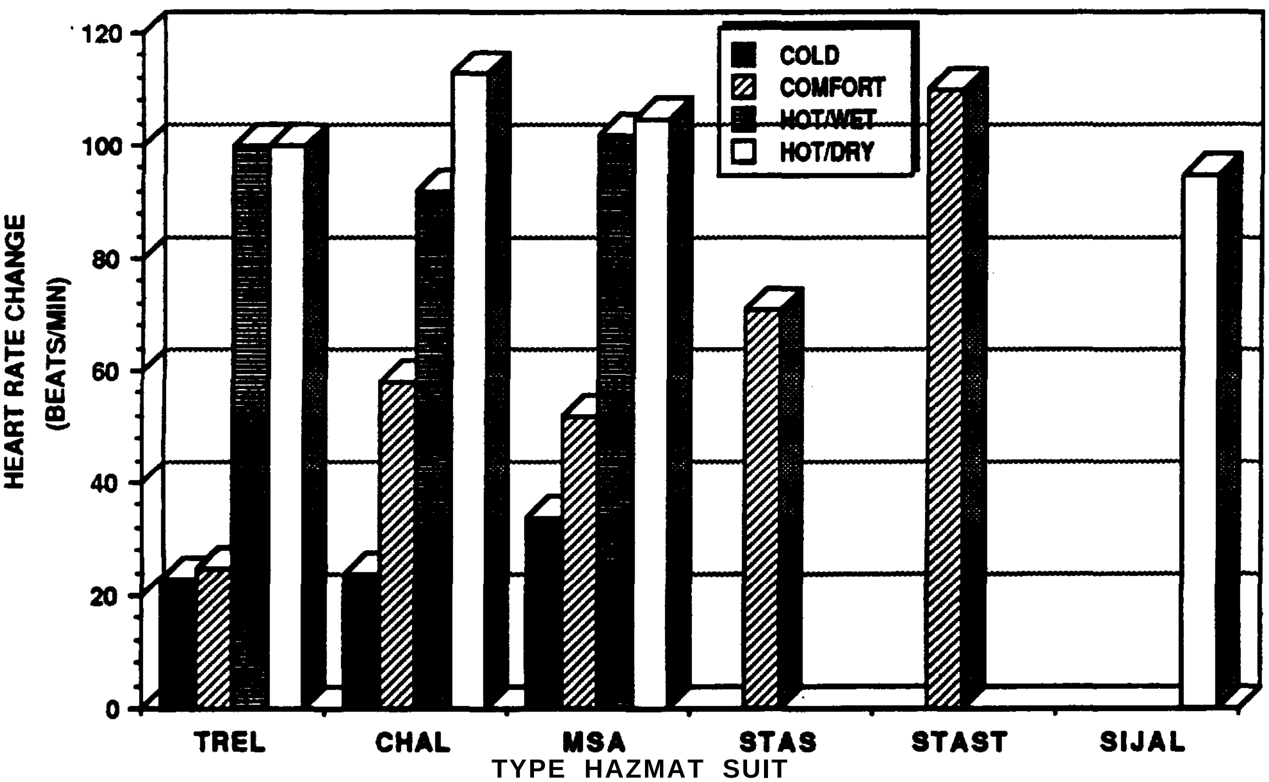

FIG 1B. EFFECT OF WORK AND CLIMATIC CONDITIONS ON HEART RATE CHANGE.

TABLE 2. FINAL HR(BEATS/MIN)

FIREFIGHTER	CONDITIONS	TRELLECHEM	CHALLENGE	MSA
1	HOT/DRY	149	183	151
2	HOT/DRY	158	175	140
3	HOT/DRY	171	187	172
4	HOT/DRY	179	173	176
5	HOT/DRY	183	179	190
	AVER	188	175	166
	STAND DEV	± 15	± 6	± 20
6	HOT/WET	208	190	162
7	HOT/WET	165	140	160
8	HOT/WET	173	157	175
9	HOT/WET	140	167	162
10	HOT/WET	185	124	165
	AVER	170	155	164
	STAND DEV	± 25	± 25	± 6
11	COMFORT	120	162	106
12	COMFORT	90	154	151
13	COMFORT	97	103	104
14	COMFORT	57	71	86
15	COMFORT	112	148	137
	AVER	95	127	117
	STAND DEV	± 24	± 39	± 24
16	COLD	87	100	100
17	COLD	123	85	72
18	COLD	72	91	91
19	COLD	90	112	113
20	COLD	109	109	136
	AVER	98	99	102
	STAND DEV	± 20	± 12	± 24

TABLE 3. HR CHANGE(BEATS/MIN)

FIREFIGHTER	CONDITIONS	TRELLECHEM	CHALLENGE	MSA
1	HOT/DRY	64	103	93
2	HOT/DRY	107	126	88
3	HOT/DRY	101	100	91
4	HOT/DRY	109	106	121
5	HOT/DRY	97	132	134
	AVER	100	113	105
	STAND DEV	± 10	±13	± 21
6	HOT/WET	134	130	102
7	HOT/WET	101	62	103
6	HOT/WET	91	76	95
9	HOT/WET	69	102	98
10	HOT/WET	107	70	110
	AVER	100	92	102
	STAND DEV	± 24	± 24	± 6
11	COMFORT	62	96	50
12	COMFORT	12	76	75
13	COMFORT	21	33	44
14	COMFORT	-3	19	30
15	COMFORT	35	66	61
	AVER	25	56	52
	STAND DEV	± 25	± 32	± 17
16	COLD	13	15	27
17	COLD	41	30	20
16	COLD	9	6	27
19	COLD	17	35	43
20	COLD	33	33	53
	AVER	23	24	34
	STAND DEV	± 14	± 12	± 14

Values plotted are an average for the five fire fighters exposed to that particular environmental condition. In Fig. 1A, the absolute heart rates measured at the end of the test are shown while wearing each HAZMAT clothing ensemble. STAS data are for the STAS Level A ensemble without the air line tether while data with the tether are shown above STAST. Figure 16 shows the heart rate change plotted for each clothing ensemble. The heart rate change is simply the difference between the beginning and final heart rates. These data are more meaningful as the beginning or resting HR values vary slightly between persons and from day to day. The individual heart rate values for each fire fighter are shown in Tables 2 and 3. The standard deviation for each clothing ensemble were tabulated for each temperature condition. Figures 2A and 2B show the response of the body core temperature to the various thermal environments. Figure 2A shows the average final rectal temperatures of fire fighters after wearing each protective ensemble. Figure 2B shows. the increase in body temperatures above resting levels. Tables 4 and 5 show the individual rectal temperatures for each fire fighter and each condition. Figures 2C and Table 6 show the change in body temperature from the final values to that measured thirty minutes after the fire fighter has undressed in a cool or comfortable room. Figure 3 and Table 7 shows the amount of sweat toss from the beginning to the end of the test period. In Figure 4 and Table 16, the beginning body weight of the fire fighters is compared daily to determine the state of the body hydration. The body's hydration status is important in the interrelationship between heat stress and the level of circulatory strain on the body. Figure 5 shows the linear relationship between work load and heart rate. If the heart rate is known, then the work bad (oxygen uptake) can be estimated. For example, a heart rate of 140 beats/min is considered very heavy work and heart rates over 160 beats/min is considered extremely heavy work. Respiration rates are also related to work bad and Table 8 lists the changed in breathing rate while wearing the various protective ensembles. Blood pressure is important as it provides the driving force for the exchange of oxygen and nutrients from the blood to the cells (Table 9). Both work and heat have an effect on blood pressure.

The amount of sweat trapped in the underclothing by each ensemble is Shown in Figure 6 and tabulated in Tables 10, 11, and 12. As the outer shell materials of these ensembles are essentially impervious to water, the only sweat loss k that which is dumped outside the clothing through the exhaust valves.

Table 13 shows the inside suit temperatures surrounding the head and result from the

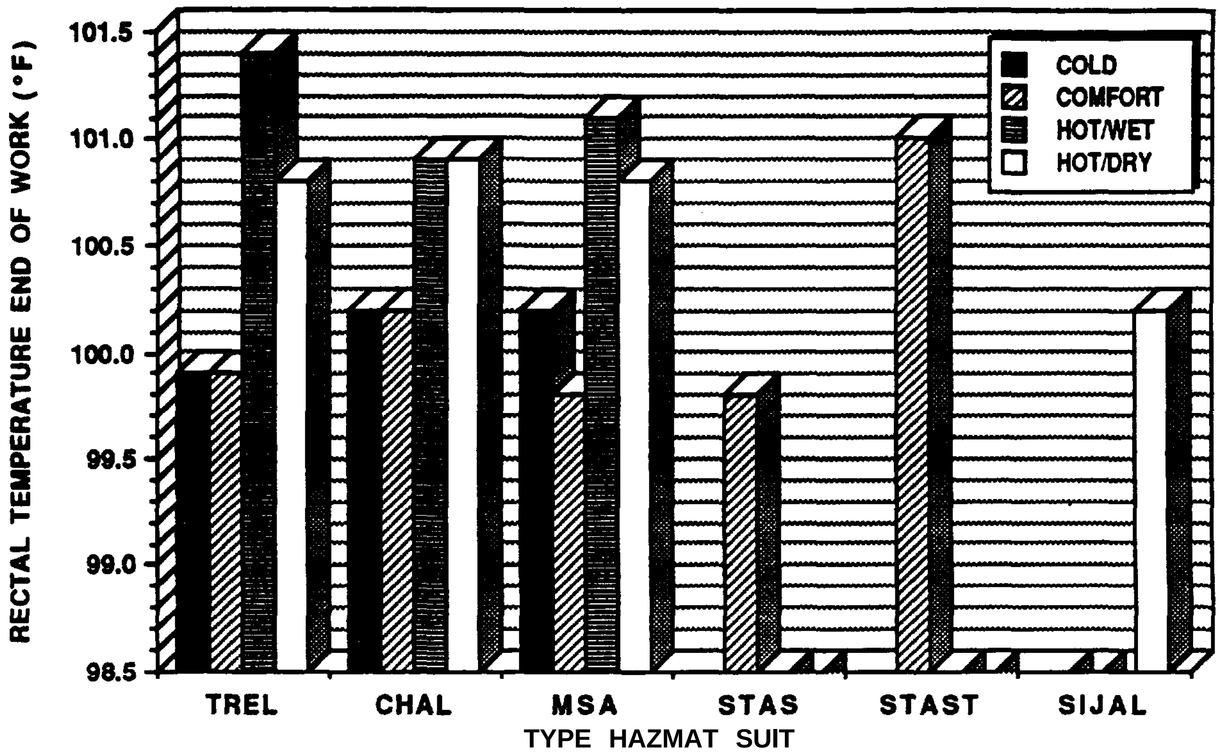

FIG.2A. EFFECT OF WORK AND CLIMATIC CONDITIONS ON ABSOLUTE RECTAL TEMPERATURE.

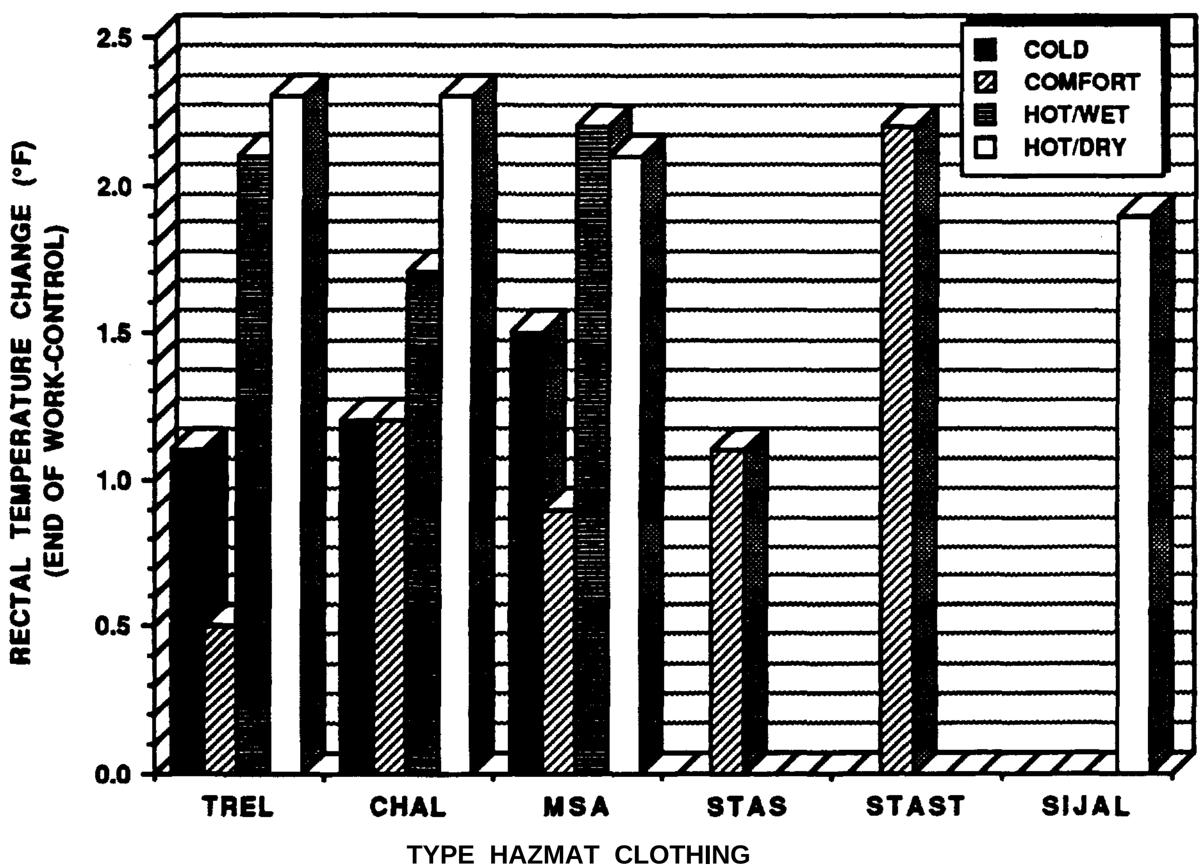

FIG.2B. EFFECT OF WORK AND CLIMATIC CONDITIONS ON RECTAL TEMPERATURE CHANGE.

TABLE 4. ABSOLUTE TR (°F)

FIREFIGHTER	CONDITIONS	TRELLECHEM	CHALLENGE	MSA
1	HOT/DRY	100.5	102.0	100.8
2	HOT/DRY	99.3	100.3	100.0
3	HOT/DRY	101.3	101.3	102.2
4	HOT/DRY	101.7	100.3	100.8
5	HOT/DRY	101.4	100.5	100.4
	AVER	100.8	100.9	100.8
	STAND DEV	± 1.0	± 0.8	± 0.8
6	HOT/WET	101.6	101.5	100.5
7	HOT/WET	101.4	100.7	101.2
8	HOT/WET	101.0	100.8	100.6
9	HOT/WET	102.0	101.1	101.8
10	HOT/WET	101.0	100.2	101.3
	AVER	101.4	100.9	101.1
	STAND DEV	± 0.4	± 0.5	± 0.5
11	COMFORT	99.8	100.8	99.8
12	COMFORT	100.0	100.2	99.8
13	COMFORT	100.0	100.3	99.8
14	COMFORT	99.8	99.8	100.0
15	COMFORT	99.7	100.2	99.7
	AVER	99.9	100.2	99.8
	STAND DEV	± 0.1	± 0.4	± 0.1
16	COLD	98.8	100.7	100.5
17	COLD	100.7	100.3	99.7
18	COLD	99.7	99.7	99.8
19	COLD	99.8	100.7	100.3
20	COLD	100.4	99.8	100.5
	AVER	99.9	100.2	100.2
	STAND DEV	± 0.7	± 0.5	± 0.4

TABLE 5. TR CHANGE (°F)

FIREFIGHTER	CONDITIONS	TRELLECHEM	CHALLENGE	MSA
1	HOT/DRY	1.9	2.8	2.0
2	HOT/DRY	1.8	1.8	1.5
3	HOT/DRY	2.8	2.8	3.1
4	HOT/DRY	2.8	1.8	2.3
5	HOT/DRY	2.6	2.5	1.5
	AVER	2.3	2.3	2.1
	STAND DEV	± 0.5	± 0.5	± 0.7
8	HOT/WET	1.8	2.0	1.3
7	HOT/WET	2.2	2.0	2.9
8	HOT/WET	1.8	1.5	1.2
9	HOT/WET	2.8	1.9	2.9
10	HOT/WET	1.9	1.1	2.8
	AVER	2.1	1.7	2.2
	STAND DEV	± 0.3	± 0.4	± 0.9
11	COMFORT	1.0	1.1	1.0
12	COMFORT	0.4	1.2	1.1
13	COMFORT	0.7	1.5	0.4
14	COMFORT	0.1	0.9	0.5
15	COMFORT	0.7	1.2	1.4
	AVER	0.5	1.2	0.9
	STAND DEV	± 0.4	± 0.2	± 0.4
18	COLD	0.3	0.8	1.7
17	COLD	1.6	1.0	1.7
18	COLD	1.7	1.2	0.9
19	COLD	0.8	1.7	1.1
20	COLD	1.2	1.5	2.1
	AVER	1.1	1.2	1.5
	STAND DEV	± 0.6	± 0.4	± 0.5

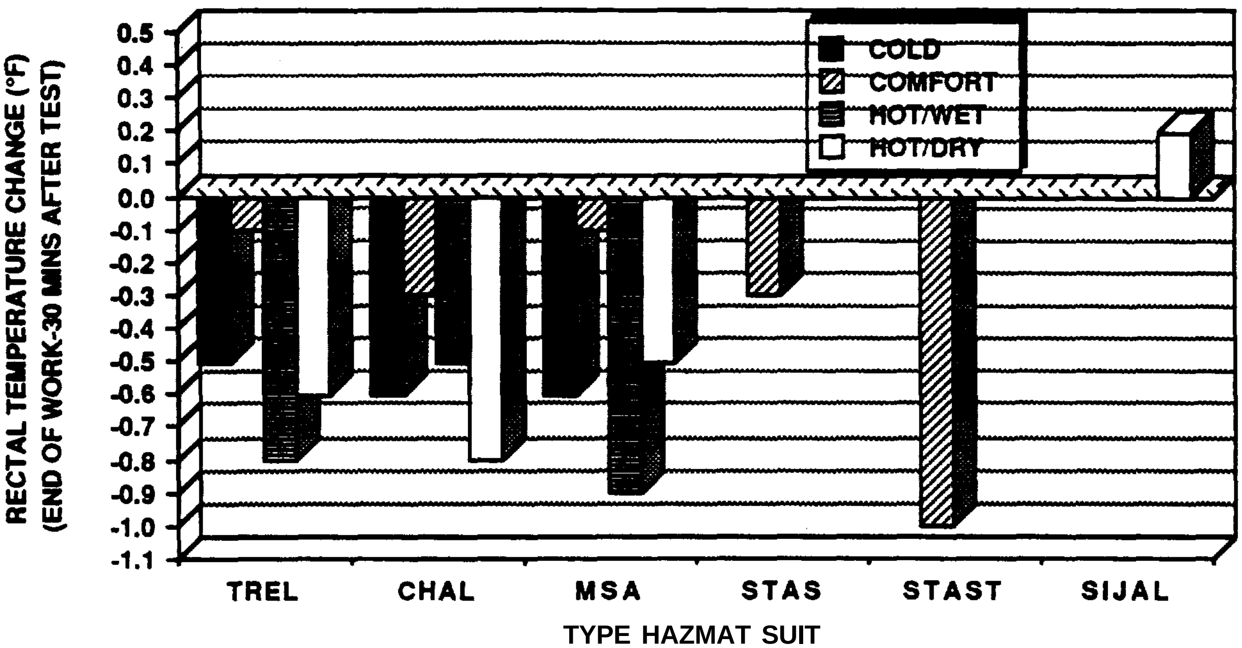

FIG. 2C. BODY COOLING AFTER WORK

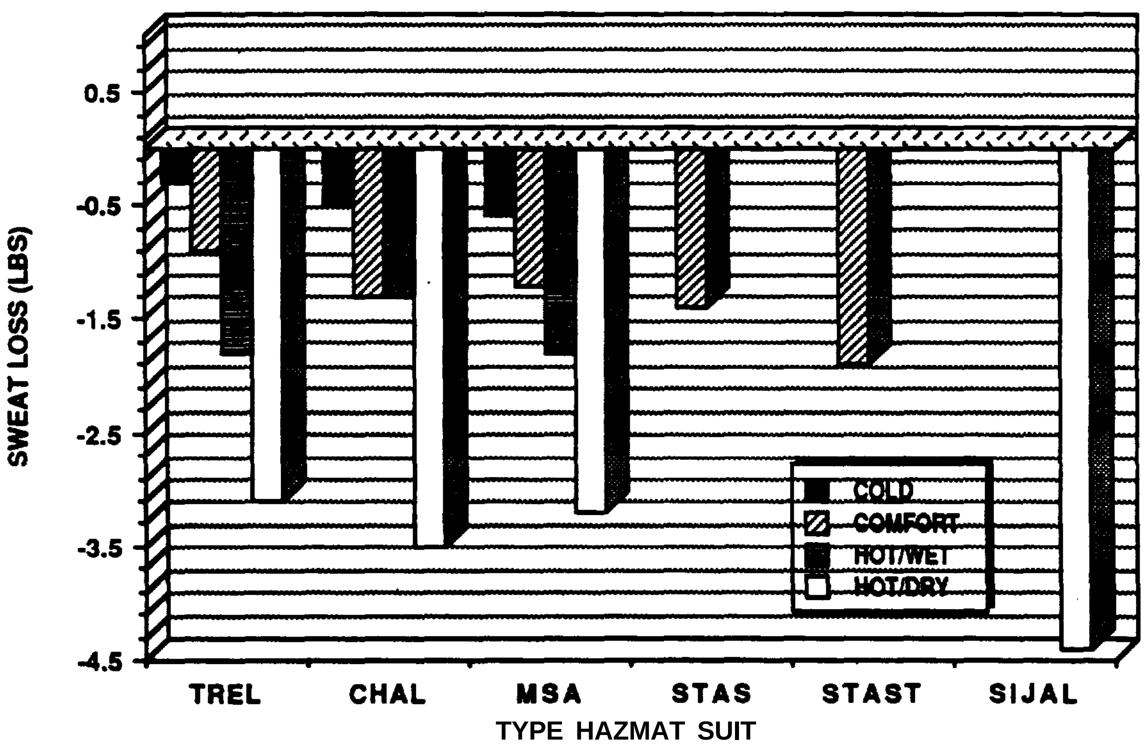

FIG. 3. SWEAT LOSS

TABLE 6. RECOVERY TR CHANGE

FIREFIGHTERS	CONDITIONS	TRELLECHEM	CHALLENGE	MSA
1	HOT/DRY	-0.7	0.0	-0.3
2	HOT/DRY	+0.2	-0.4	0.0
3	HOT/DRY	-1.2	-1.5	0.0
4	HOT/DRY	0.0	-0.7	-0.8
5	HOT/DRY	0.0	-0.7	-0.4
	AVER	-0.6	-0.8	-0.5
	STAND DEV	± 0.7	± 0.5	± 0.3
6	HOT/WET	-1.0	-1.0	-0.8
7	HOT/WET	-1.1	-0.6	-1.5
8	HOT/WET	-0.4	-0.3	-0.5
9	HOT/WET	-0.7	-0.4	-1.1
10	HOT/WET	-0.7	-0.2	-0.8
	AVER	-0.6	-0.5	-0.9
	STAND DEV	± 0.3	± 0.3	± 0.4
11	COMFORT	-0.1	-0.6	-0.1
12	COMFORT	-0.2	-0.7	-0.7
13	COMFORT	-0.2	-0.1	0.0
14	COMFORT	-0.2	0.0	-0.1
15	COMFORT	0.0	+0.l	+0.2
	AVER	-0.1	-0.3	-0.1
	STAND DEV	± 0.1	± 0.4	± 0.3
18	COLD	+0.3	-0.8	-0.9
17	COLD	-0.9	-0.8	-0.3
18	COLD	-0.9	0.0	-0.2
19	COLD	-0.3	-0.5	-0.4
20	COLD	-0.7	-0.8	-1.2
	AVER	-0.5	-0.6	-0.6
	STAND DEV	± 0.5	± 0.3	± 0.4

TABLE 7. NUDE WEIGHT LOSS (LBS)

FIREFIGHTER	CONDITIONS	TRELLECHEM	CHALLENGE	MSA
1	HOT/DRY	-2.2	-2.7	-3.4
2	HOT/DRY	-3.2	-3.7	-4.0
3	HOT/DRY	-3.4	-5.2	-2.7
4	HOT/DRY	-4.1	-3.4	-3.7
5	HOT/DRY	-2.5	-2.6	-2.2
	AVER	-3.1	-3.5	-3.2
	STAND DEV	± 0.6	± 1.0	± 0.7
8	HOT/WET	-2.4	-0.9	-2.0
7	HOT/WET	-2.7	-2.2	-2.8
6	HOT/WET	-0.9	-1.4	-1.3
9	HOT/WET	-1.6	-0.7	-0.8
10	HOT/WET	-1.4	-1.3	-2.3
	AVER	-1.8	-1.3	-1.8
	STAND DEV	± 0.7	± 0.6	± 0.8
11	COMFORT	-1.2	-1.7	-1.0
12	COMFORT	-0.8	-1.1	-1.2
13	COMFORT	-0.8	-1.0	-0.8
14	COMFORT	-1.2	-0.9	-1.8
15	COMFORT	-0.7	-2.0	-1.2
	AVER	-0.9	-1.3	-1.2
	STAND DEV	± 0.2	± 0.5	± 0.3
18	COLD	-0.1	-0.5	-0.5
17	COLD	-0.5	-0.8	-0.8
18	COLD	-0.4	-0.4	-0.3
19	COLD	-0.3	-0.4	-0.5
20	COLD	-0.3	-0.4	-0.8
	AVER	-0.3	-0.5	-0.6
	STAND DEV	± 0.1	± 0.2	± 0.2

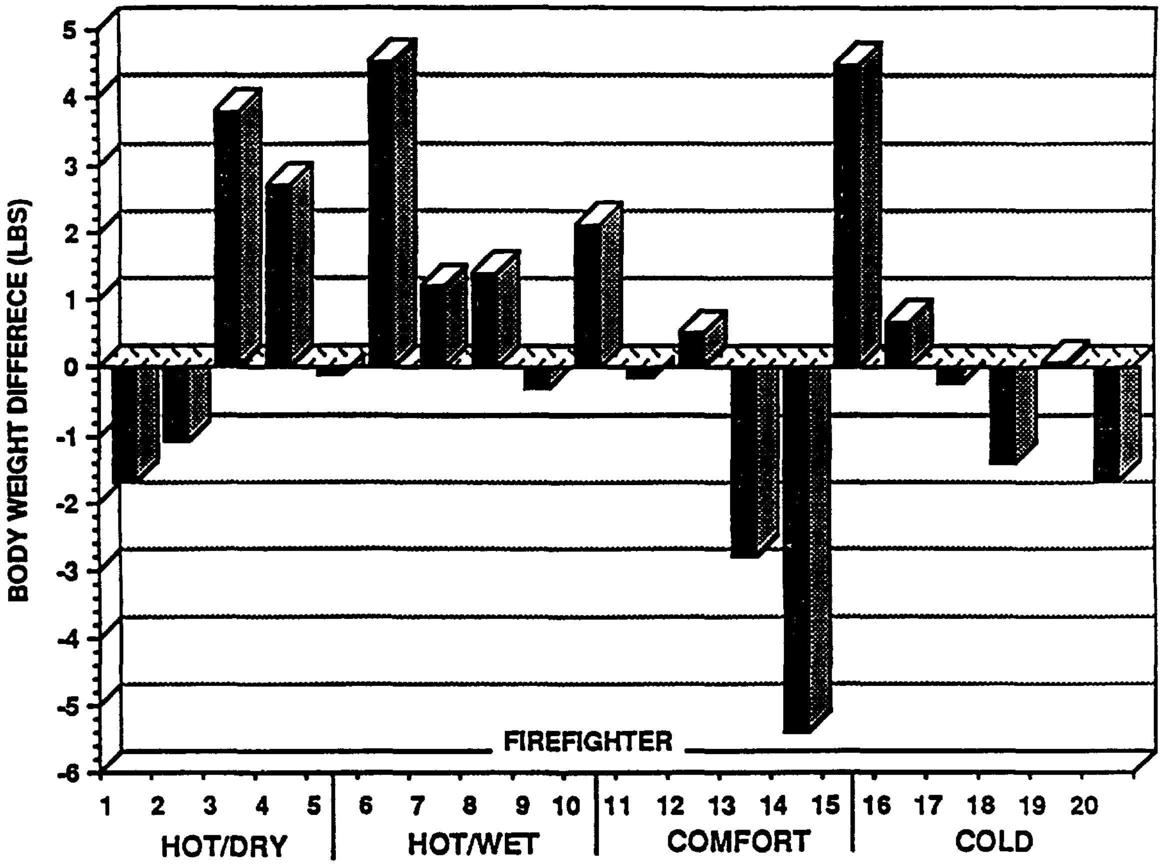

FIG. 4. CONTROL BODY WEIGHT CHANGE BETWEEN DAY 1 AND DAY 3.

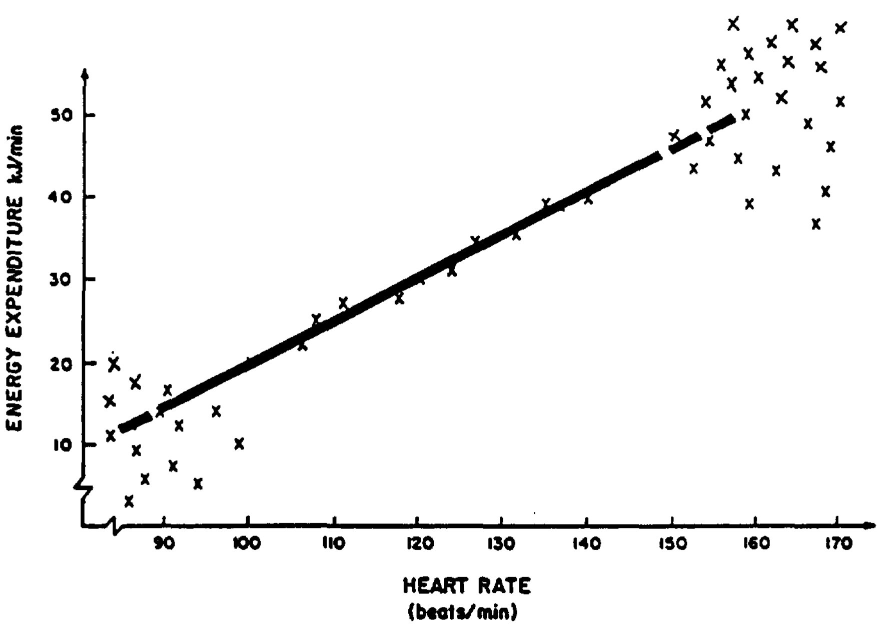

FIG. 5. RELATIONSHIP BETWEEN OXYGEN UPTAKE EXPRESSED AS ENERGY EXPENDITURE AND HEART RATE (KROEMER Et Al, 1986).

TABLE 8. RR CHANGE (BREATHS/MIN)

FIRE FIGHTER	CONDITIONS	TRELLECHEM	CHALLENGE	MSA
1	HOT/DRY	10	15	7
2	HOT/DRY	6	10	8
3	HOT/DRY	10	0	10
4	HOT/DRY	12	4	10
5	HOT/DRY	16	10	6
	AVER	11	8	6
	STAND DEV	± 4	± 6	± 2
6	HOT/WET	8	6	10
7	HOT/WET	12	8	12
8	HOT/WET	10	8	10
9	HOT/WET	10	14	16
10	HOT/WET	16	6	12
	AVER	11	8	12
	STAND DEV	± 3	± 3	± 2
11	COMFORT	4	8	2
12	COMFORT	10	12	6
13	COMFORT	4	2	10
14	COMFORT	13	10	6
15	COMFORT	12	0	6
	AVER	9	6	6
	STAND DEV	± 4	± 5	± 3
16	COLD	2	0	8
17	COLD	0	4	0
18	COLD	0	6	4
19	COLD	0	12	0
20	COLD	2	0	20
	AVER	1	4	8
	STAND DEV	± 1	± 5	± 8

TABLE 9. BP CHANGE(SYS/DIA)

FIRE FIGHTER	CONDITIONS	TRELLECHEM	CHALLENGE	MSA
1	HOT/DRY	22/-3	108/92	39/3
2	HOT/DRY	15/-17	11/-18	130/163
3	HOT/DRY	15/-3	33/-7	68/104
4	HOT/DRY	1/-26	43/-8	38/-10
5	HOT/DRY	-3/-26	18/-4	3/-14
	AVER	10/-15	43/11	56/49
	STAND DEV	±11/12	±39/46	±48/80
6	HOT/WET	211-17	231-16	11/-11
7	HOT/WET	71-8	6/12	-2/19
8	HOT/WET	-5/13	-2/-1	14/-3
9	HOT/WET	-18/-18	-10/-12	-10/-4
10	HOT/WET	12/-8	15/12	17/-3
	AVER	3/-13	6/-3	6/-8
	STAND DEV	±15/5	±13/11	±12/7
11	COMFORT	18/24	26/-2	.14/14
12	COMFORT	19/22	30/14	-6/4
13	COMFORT	0/30	-14/10	22/20
14	COMFORT	44/20	28/20	40/32
15	COMFORT	0/22	-16/-8	14/20
	AVER	16/14	5/7	17/18
	STAND DEV	±16/12	±24/12	±17/10
16	COLD	28/22	0/10	10/20
17	COLD	20/14	28/9	30/16
18	COLD	30/20	30/20	-8/19
19	COLD	14/4	2/18	10/-5
20	COLD	8/8	30/21	10/ 16
	AVER	20/14	18/16	10/13
	STAND DEV	±9/8	±16/6	±13/10

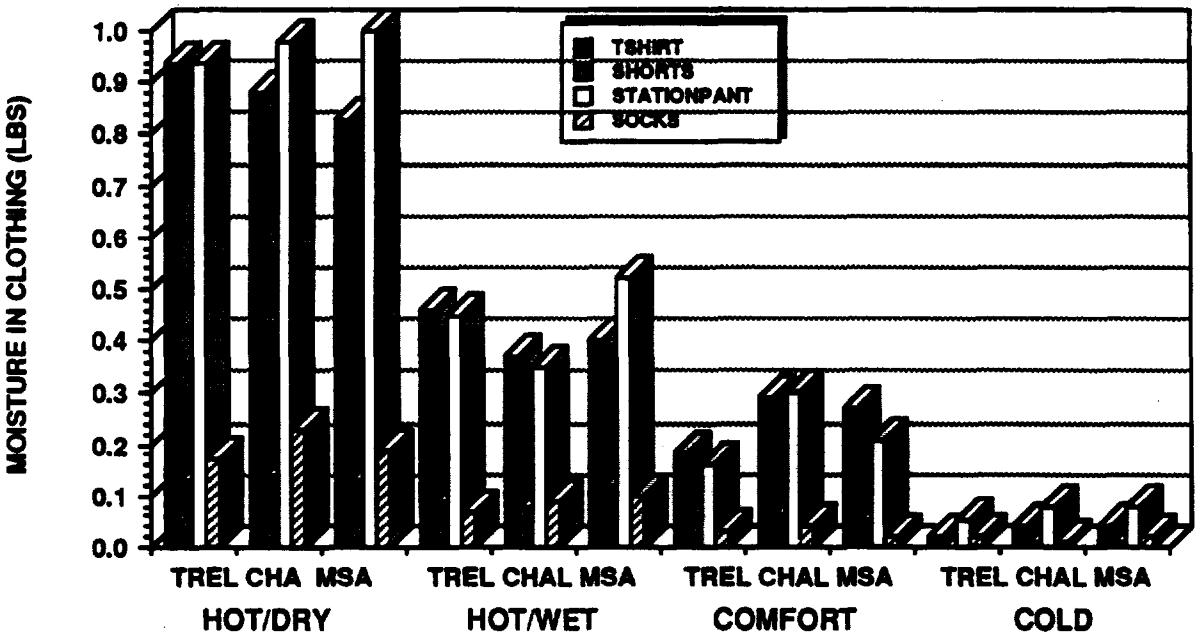

FIGURE 6. AVERAGE MOISTURE GAIN IN CLOTHING ITEMS OF ENSEMBLES.

TABLE 10. TREL CLOTH.GAIN(LBS)

FIRE FIGHTER	CONDITIONS	T SHIRT	SHORTS	STAT.PANT	SOCKS	TOTAL WGT
1	HOT/DRY	0.65	0.11	0.87	0.11	1.74
2	HOT/DRY	1.01	0.18	1.00	0.17	2.36
3	HOT/DRY	0.97	0.10	0.97	0.23	2.27
4	HOT/DRY	1.24	0.18	1.16	0.15	2.71
5	HOT/DRY	0.81	0.10	0.69	0.17	1.77
	AVER	0.94	0.13	0.94	0.17	2.17
	STAND DEV	± 0.22	± 0.04	± 0.17	± 0.04	± 0.41
8	HOT/WET	0.61	0.06	0.73	0.02	1.42
7	HOT/WET	0.60	0.12	0.51	0.20	1.43
8	HOT/WET	0.32	0.08	0.33	0.07	0.60
9	HOT/WET	0.28	0.09	0.24	0.04	0.65
10	HOT/WET	0.51	0.11	0.45	0.04	1.11
	AVER	0.46	0.09	0.45	0.07	1.08
	STAND DEV	± 0.16	± 0.02	± 0.19	± 0.07	± 0.35
11	COMFORT	0.30	0.06	0.22	0.06	0.64
12	COMFORT	0.10	0.02	0.06	0.02	0.20
13	COMFORT	0.12	0.18	0.16	0.02	0.46
14	COMFORT	0.24	0.03	0.24	0.02	0.53
15	COMFORT	0.12	0.02	0.14	0.02	0.30
	AVER	0.18	0.08	0.16	0.03	0.43
	STAND DEV	± 0.09	± 0.08	± 0.07	± 0.02	± 0.18
16	COLD	0.02	0.00	0.06	0.04	0.12
17	COLD	0.04	0.00	0.06	0.00	0.12
18	COLD	0.02	0.00	0.06	0.00	0.08
19	COLD	0.02	0.00	0.06	0.04	0.12
20	COLD	0.00	0.00	0.00	0.00	0.00
	AVER	0.02	0.00	0.05	0.02	0.09
	STAND DEV	± 0.01	± 0.00	± 0.03	± 0.02	± 0.05

TABLE 11. CHAL CLOTH.GAIN(LBS)

FIRE FIGHTER	CONDITIONS	T SHIRT	SHORTS	STAT.PANT	SOCKS	TOTAL WGT
1	HOT/DRY	0.64	0.05	0.89	0.13	1.71
2	HOT/DRY	1.07	0.25	1.13	0.26	2.71
3	HOT/DRY	1.11	0.15	1.23	0.37	2.86
4	HOT/DRY	0.92	0.18	1.06	0.20	2.36
5	HOT/DRY	0.67	0.09	0.57	0.20	1.53
	AVER	0.66	0.14	0.98	0.23	2.23
	STAND DEV	±0.22	± 0.08	±0.26	±0.09	±0.59
6	HOT/WET	0.38	0.07	0.43	0.05	0.93
7	HOT/WET	0.56	0.12	0.43	0.17	1.28
8	HOT/WET	0.37	0.09	0.42	0.10	0.96
9	HOT/WET	0.19	0.07	0.25	0.04	0.55
10	HOT/WET	0.34	0.08	0.23	0.08	0.71
	AVER	0.37	0.08	0.35	0.09	0.69
	STAND DEV	±013	±0.02	±0.10	±0.05	±0.28
11	COMFORT	0.36	0.10	0.50	0.06	1.02
12	COMFORT	0.20	0.04	0.16	0.04	0.44
13	COMFORT	0.16	0.06	0.20	0.04	0.48
14	COMFORT	0.22	0.04	0.14	0.02	0.42
15	COMFORT	0.48	0.08	0.52	0.04	1.12
	AVER	0.29	0.06	0.30	0.04	0.70
	STAND DEV	±0.13	±0.03	±0.19	±0.01	±0.34
16	COLD	0.04	0.02	0.06	0.02	0.14
17	COLD	0.12	0.02	0.14	0.02	0.30
18	COLD	0.02	0.02	0.06	0.00	0.10
19	COLD	0.02	0.00	0.14	0.00	0.16
20	COLD	0.00	0.00	0.00	0.00	0.00
	AVER	0.04	0.01	0.08	0.01	0.14
	STAND DEV	± 0.05	± 0.01	± 0.06	± 0.01	±0.11

TABLE 12. MSA CLOTH.GAIN(LBS)

FIRE FIGHTER	CONDITIONS	T SHIRT	SHORTS	STAT.PANT	SOCKS	TOTAL WGT
1	HOT/DRY	0.66	0.10	0.97	0.15	1.88
2	HOT/DRY	0.93	0.18	1.05	0.14	2.28
3	HOT/DRY	0.96	0.11	1.02	0.19	2.28
4	HOT/DRY	1.14	0.18	1.10	0.21	2.63
5	HOT/DRY	0.48	0.08	0.84	0.27	1.67
	AVER	0.83	0.13	1 .00	0.19	2.15
	STAND DEV	±0.26	±0.04	±0.10	±0.05	± 0.38
6	HOT/WET	0.51	0.06	0.68	0.02	1.27
7	HOT/WET	0.42	0.24	0.89	0.30	1.85
8	HOT/WET	0.30	0.07	0.25	0.05	0.67
9	HOT/WET	0.21	0.10	0.23	0.02	0.56
10	HOT/WET	0.58	0.13	0.53	0.13	1.37
	AVER	0.40	0.12	0.52	0.10	1.14
	STAND DEV	±0.15	±0.07	±0.28	±0.12	±0.53
11	COMFORT	0.24	0.06	0.18	0.02	0.50
12	COMFORT	0.18	0.04	0.16	0.04	0.42
13	COMORT	0.24	0.06	0.16	0.02	0.48
14	COMFORT	0.38	0.02	0.32	0.00	0.72
15	COMORT	0.32	0.06	0.24	0.02	0.64
	AVER	0.27	0.05	0.21	0.02	0.55
	STAND DEV	±0.08	±0.02	±0.07	±0.01	±0.12
16	COLD	0.02	0.00	0.04	0.02	0.08
17	COLD	0.10	0.02	0.16	0.02	0.30
18	COLD	0.02	0.00	0.06	0.00	0.08
19	COLD	0.02	0.02	0.08	0.02	0.14
20	COLD	0.06	0.00	0.08	0.02	0.16
	AVER	0.04	0.01	0.08	0.02	0.15
	STAND DEV	±0.04	±0.01	±0.05	±0.01	±0.09

TABLE 13. INSIDE SUIT TEMP(°F)

FIREFIGHTER	CONDITIONS	TRELLECHEM	CHALLENGE	MSA
1	HOT/DRY	105.4	107.7	103.3
2	HOT/DRY	105.0	106.4	107.5
3	HOT/DRY	107.9	109.4	107.5
4	HOT/DRY	107.0	105.5	107.2
5	HOT/DRY	133.9	108.3	102.2
	AVER	105.8	107.5	105.5
	STAND DEV	±1.6	±1.5	±2.6
6	HOT/WET	101.3	92.3	92.6
7	HOT/WET	98.5	92.8	95.1
8	HOT/WET	96.2	96.0	89.8
9	HOT/WET	90.8	91.5	91.0
10	HOT/WET	87.8	86.4	95.3
	AVER	94.9	91.8	92.8
	STAND DEV	± 5.5	±3.5	±2.4
11	COMFORT	82.0	82.7	75.9
12	COMFORT	76.8	75.8	82.8
13	COMFORT	78.1	77.4	83.2
14	COMFORT	83.9	73.0	82.6
15	COMFORT	72.4	85.0	74.2
	AVER	78.6	78.8	79.7
	STAND DEV	±4.5	±5.0	±4.3
16	COLD	62.0	60.5	46.1
17	COLD	53.1	53.2	66.0
18	COLD	63.0	62.1	56.3
19	COLD	47.4	57.2	62.7
20	COLD	44.5	48.3	61.9
	AVER	54.0	56.3	58.6
	STAND DEV	±8.4	±5.6	±7.8

interaction of the dry bulb and globe temperatures (Table 14). These inside suit temperatures are generally the same or higher than ambient temperatures during the hot exposures and warmer during the cold exposures. Table 15 provides an insight into the oxygen requirements to perform this simulated HAZMAT work. The average values show the amount of air used is fairly constant regardless of climatic conditions or clothing worn. Various dynamic anthropometric measurements were taken to evaluate the encumberance of the various clothing ensembles on range of motion. The effect of the design of these protective ensembles are readily apparent in Figures 7 and 8. In Figure 7, for example, the overhead reach and arm reach show the inhibiting effect of a Dolman sleeve design (MA).

Tables 17 to 22 lists the individual anthropometric data for each fire fighter. In Tables 23 and 24 these individual data are averaged in term of absolute values (inches) and percentage change from control values for each clothing ensemble. Table 25 compared all anthropometric data from fire fighters and are compared to larger known data bases of miners, air traffic controllers and USAF flyers.

DISCUSSION

The two major findings of this study are the magnitude of the physiologic impact of external environmental factors on the working fire fighter and the difference in effort to perform work while wearing the various HAZMAT protective clothing ensembles.

In a totally encapsulated clothing system, the outside surrounding air envelope can play a signifcant role in the physiologic state of the fire fighter. The impact of thermal transmission from the external environment through the outer clothing shell can be readily seen when the physiological responses are compared to the dry bulb and globe temperatures (reflection of mean radiant temperature) levels. Inside suit temperatures in hot/dry and hot/wet conditions can exceed ambient levels because of the high radiant temperatures (GT). These suit temperatures exceeded 111°F on several occasions and the fire fighters in hot/dry conditions reported the inside of the suit was hot to the touch making it uncomfortable. One person reported “the top of his head was burning” and had to hold the suit hood off of his head to alleviate the problem. But, the humidity in the external surrounding air envelope as well as wind velocity can also affect the heat transfer rate through the outer shell material. The reason is that at any given temperature, the more moisture vapor contained in the air, the greater the heat capacity of that volume of air.

TABLE 14. SUMMARY OF CLIMATIC CONDITIONS

	ENVIRONMENTAL PARAMETERS					
	DRY BULB(C°)	WET BULB(°)	HUMIDITY (%RH)	GLOBE TEMP.(°)	WBGT (°C)	WIND VEL.(M/MIN)
A .HOT/DRY						
1. CHAL	42.2	27.4	32	56.3	34.8	108
2. MSA	40.2	28.2	40	53.1	33.9	92
3. TREL	41.2	27.3	35	52.8	34.4	113
4. SIJAL*	39.4	25.6	36	52.8	32.5	161
AVERAGE	40.8	27.1	36	53.8	33.9	119
B. HOT/WET						
1. CHAL	30.1	26.2	75	35.9	28.5	108
2. MSA	32.0	26.3	65	40.0	29.6	74
3. TREL	34.0	26.1	55	41.0	29.8	113
AVERAGE	32.0	26.2	65	39.0	29.3	98
C .COMFORTABLE						
1. CHAL	22.8	16.3	51	30.3	19.8	185
2. MSA	21.1	15.7	58	28.6	18.8	230
3. TREL	21.1	.15.7	58	29.4	19.0	150
4. STASAF* (NO TETHER)	25.2	16.9	43	30.5	20.2	150
5. STASAFE* (TETHER)	27.2	17.0	37	33.7	21.4	200
AVERAGE	23.5	16.3	49	30.5	19.8	183

NOTE: * REPRESENTS ONLY DATA FROM ONE FIRE FIGHTER.

TABLE 15. SCSA PRESS.DROP(PSI)

FIREFIGHTER	CONDITIONS	TRELLECHEM	CHALLENGER	MSA
1	HOT/DRY	2100	2100	2750
2	HOT/DRY	2100	2100	2300
3	HOT/DRY	2400	2600	2500
4	HOT/DRY	3300	2000	2100
5	HOT/DRY	2350	2100	3050
	AVER	2450	2180	2540
	STAND DEV	±495	±239	±373
6	HOT/WET	3500	2900	2950
7	HOT/WET	3000	2900	3000
6	HOT/WET	2100	2200	2600
9	HOT/WET	2300	2450	2600
10	HOT/WET	2700	2800	2700
	AVER	2720	2650	2770
	STAN DEV	±559	±312	±192
11	COMFORT	2400	2100	2600
12	COMFORT	3600	3600	3500
13	COMFORT	2500	2800	2300
14	COMFORT	2300	2350	2500
15	COMFORT	2500	2300	3200
	AVER	2660	2830	2820
	STAND DEV	±532	±600	±507
16	COLD	2700	2400	3400
17	COLD	1900	2200	2300
16	COLD	2200	2400	2500
19	COLD	3100	3000	3000
20	COLD	2500	3400	3200
	AVER	2460	2680	2880
	STAND DEV	±460	±502	±466

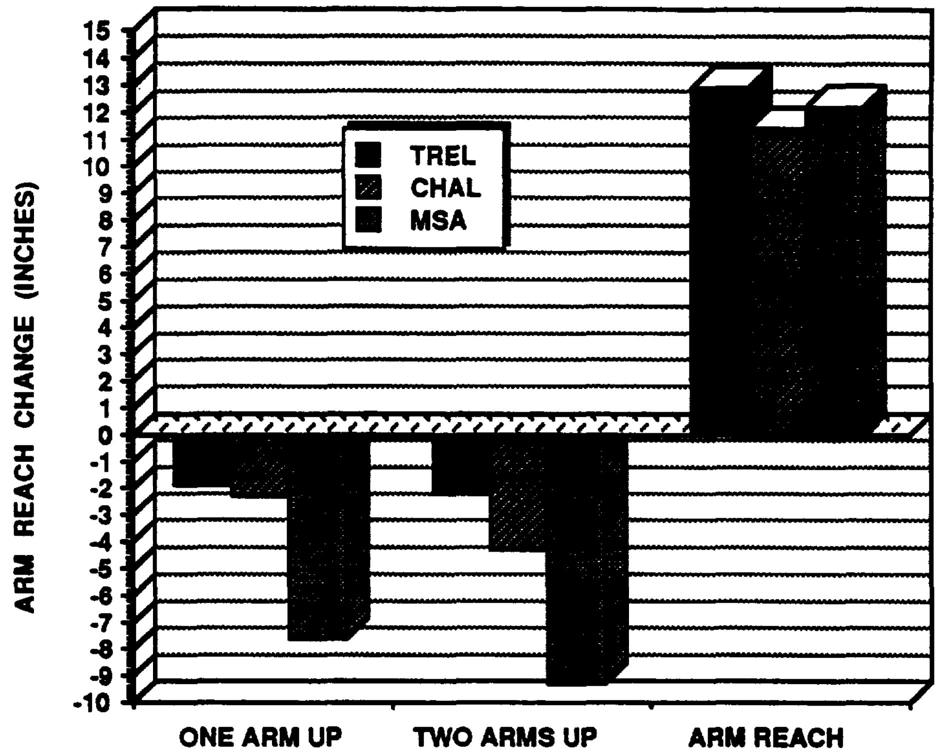

FIGURE 7. DIFFERENCE ARM REACH WITH AND WITHOUT CLOTHING.

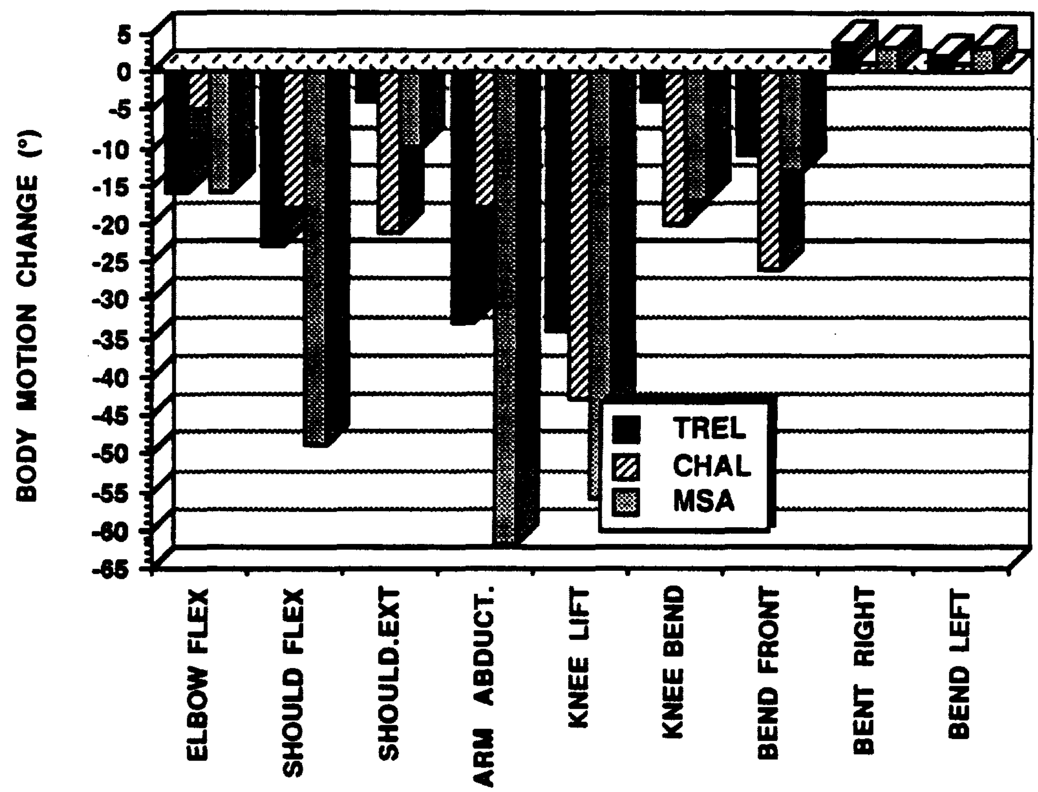

FIGURE 8. DIFFERENCE BODY MOTION WITH AND WITHOUT CLOTHING.

TABLE16. PREBODY WGT(LBS)

FIREFIGHTER	CONDITIONS	TESTDAY 1	TESTDAY 2	TESTDAY 3	DAY1,3 DIFF
1	HOT/DRY	162.71	161.70	161.00	-1.71
2	HOT/DRY	182.69	179.78	181.59	-1.10
3	HOT/DRY	193.86	197.16	197.65	3.79
4	HOT/DRY	184.27	186.47	186.98	2.71
5	HOT/DRY	158.62	156.82	156.51	-0.11
	AVER	176.03	176.39	176.75	0.72
	STAND DEV	± 15.7	± 16.9	± 17.5	± 2.4
6	HOT/WET	252.30	259.10	256.80	4.50
7	HOT/WET	193.80	193.90	195.00	1.20
8	HOT/WET	157.60	159.00	159.00	1.40
9	HOT/WET	106.20	106.00	105.90	-0.30
10	HOT/WET	189.20	190.00	191.30	2.10
	AVER	179.82	181.60	181.60	1.78
	STAND DEV	± 53.5	± 55.8	±55.2	± 1.6
11	COMFORT	173.32	173.06	173.16	-0.16
12	COMFORT	213.12	211.40	213.82	0.50
13	COMFORT	164.46	162.00	181.64	-2.82
14	COMFORT	218.08	211.38	210.64	-5.44
15	COMFORT	196.22	198.04	200.58	4.46
	AVER	192.64	191.18	191.93	-0.7
	STAND DEV	± 23.2	± 22.6	± 23.3	± 3.7
16	COLD	172.42	173.08	171.74	0.66
17	COLD	252.00	252.30	251.76	-0.24
18	COLD	251.28	250.18	249.86	-1.42
19	COLD	186.12	185.70	186.06	0.06
20	COLD	152.80	150.48	151.10	-1.70
	AVER	202.92	202.35	202.10	-0.52
	STAND DEV	± 46.0	± 46.4	± 46.2	± 1.00

TABLE 17.CHAL-NUDE REACH(IN)

FIREFIGHTER	1 ARM UP	2 ARMS UP	1 ARM REACH
1	-3.0	-4.8	+6.5
2	-0.9	-2.1	0.0
4	-3.9	-5.6	0.0
6	-7.2	-7.6	0.0
7	-2.7	-2.2	0.0
6	-3.0	-5.9	0.0
9	+0.1	-2.1	0.0
10	-5.9	-5.5	0.0
11	-4.7	-7.0	+7.6
12	-0.2	-3.1	+10.1
13	-1.0	-4.0	+8.7
14	-4.2	-4.9	+49.7
15	-2.1	-2.0	+47.5
16	+1.9	-2.8	-1.9
17	-0.7	-7.6	-2.1
16	-2.3	-3.5	-1.0
19	-1.1	-5.2	-1.9
20	-0.5	-2.1	+0.9
AVERAGE	-2.3	-4.3	+11.4
STAND DEV	±2.3	±1.9	±19.0

TABLE 18.TREL-NUDE REACH (IN)

FIREFIGHTER	1 ARM UP	2 ARMUP	1 ARM REACH
1	-1.9	-3.0	0.0
2	-0.5	-0.2	0.0
4	-0.8	-1 .5	0.0
6	-4.7	-5.6	0.0
7	-0.5	+0.2	0.0
8	-2.9	-4.0	0.0
9	-1.8	-1.9	0.0
10	-4.4	-3.7	0.0
11	-1.1	-1.9	+6.9
12	-3.4	-3.5	+10.6
13	-0.9	-0.7	+6.7
14	-3.2	-3.9	+49.8
15	+0.8	-0.1	+47.7
18	+0.7	-1.1	-0.6
17	0.0	-1.8	+0.4
18	-3.5	-4.1	+1.6
19	-3.7	-2.5	+2.4
20	±1.7	+0.2	+1.0
AVERAGE	-1.9	-2.2	+12.9
STAND DEV	±1.7	±1.7	±19.3

TABLE 19. MSA-NUDE REACH(IN)

FIREFIGHTER	1 ARM UP	2 ARM UP	1 ARM REACH
1	-3.3	-4.6	0.0
2	-5.4	-5.3	0.0
4	-11.9	-13.3	0.0
6	-11.9	-11.5	0.0
7	-11.4	-10.9	0.0
8	-12.7	-13.0	0.0
9	-2.5	-3.0	0.0
10	-8.0	-7.3	0.0
11	-6.6	-5.4	+5.5
12	-7.4	-25.5	+10.6
13	-3.6	-5.1	+8.2
14	-10.0	-11.9	+48.3
15	-5.7	-6.0	+46.7
16	-1.5	-3.1	+0.1
17	-8.9	-13.2	-0.7
18	-11.9	-12.4	-0.9
19	-10.4	-10.9	+3.7
20	-3.9	-5.0	+0.4
AVERAGE	-7.6	-9.3	+12.2
STAND DEV	±3.7	±5.5	±19.0

TABLE 2O.CHAL-NUDE MOTION

FIREFIGHTER	ELBOW FLEX	SHOULDER FLEX	SHOULD.EXT	ARM ABDUCT	KNEE LIFT	KNEE BEND	BEND FORWARD	BEND RIGHT	BEND LEFT
1	0	-6	-36	-91	0	0	-56	-12	-14
2	0	-30	-29	-24	0	0	-16	+6	+ 7
4	0	-29	-3	+6	0	0	-19	+16	+9
6	0	-63	-9	-14	0	0	-36	- 7	-2
7	0	-3	-31	-42	0	0	-12	+14	+15
6	0	-13	-10	-22	0	0	-40	-3	-3
9	0	+3	-23	-23	0	0	-32	-6	0
10	0	-20	+16	-16	0	0	-31	+11	+1
11	-10	-33	-30	-66	-46	-45	+3	+7	+10
12	-6	-33	-39	-20	-40	-14	-37	-10	-6
13	-16	-16	-23	-9	-64	-14	-26	-6	-2
14	-14	-11	-25	-44	-49	-12	-50	+3	+2
15	-15	-11	-5	-21	-43	-44	-40	-10	- 3
16	+l	-13	-63	-71	-26	-27	-27	+6	+3
17	+16	-15	-21	-44	-46	-6	-29	-2	+ 6
18	- 7	-10	-26	-93	-43	-5	+1	+1	+ 2
19	+2	-12	-10	-76	-40	-30	-6	+5	+ 4
20	0	-13	-19	-13	-34	-3	-11	+10	-6
AVERAGE	-5	-16	-21	-16	-43	-20	-26	+1	+1
STAND DEV	±10	±13	±17	±30	±10	±16	±17	±9	±7

TABLE 21.TREL-NUDE MOTION

FIREFIGHTER	ELBOW FLEX	SHOULDER FLEX	SHOULDER FLEX	ARM ABDUCT	KNEE LIFT	KNEE BEND	BEND FOWARD	BEND RIGHT	BEND LEFT
1	0	-35	+26	-83	0	0	-16	+7	-3
2	0	-51	+6	-66	0	0	+14	+18	+5
4	0	-30	-7	+7	0	0	+5	+I9	+12
6	0	-16	+1	-22	0	0	-36	-6	-14
7	0	-17	-14	-41	0	0	+3	+13	+6
6	0	-26	-20	-10	0	0	-14	-1	-1
9	0	-9	+3	-40	0	0	-32	-2	+5
10	0	-28	+3	-26	0	0	-23	+6	+1
11	-34	-47	+9	-46	-24	-18	+7	+21	+17
12	-15	-40	-16	-20	-36	-8	-29	-12	-15
13	+1	-45	-18	-21	-67	-5	-7	-2	+1
14	-13	-27	-16	-26	-43	+7	-35	+4	+3
15	-23	-13	-2	-11	-21	-17	-4	-12	+2
16	-16	+7	-25	-24	-29	-10	-6	0	+2
17	-2	-11	+5	-46	-36	0	-2	+6	+4
16	-29	-13	-1	-74	-34	+10	-12	-1	+5
19	-28	-6	-1	-17	-28	+10	-6	+5	+5
20	-4	-20	-4	-12	-20	-7	-7	+5	0
AVERAGE	-16	-23	-4	-33	-34	-4	-11	+4	+2
STAND DEVIA.	±12	±I5	±13	±24	±13	±10	±15	±10	±8

TABLE 22. MSA-NUDE MOTION(°)

FIREFIGHTER	ELBOW FLEX	SHOULDER FLEX	SHOULD.EXT	ARM ABDUCT	KNEE LIFT	KNEE BEND	BEND FORWARD	BEND RIGHT	BEND LEFT
1	0	-26	+13	-115	0	0	-16	+1	+10
2	0	-53	-22	-50	0	0	+14	+14	+12
4	0	-64	+10	-66	0	0	+ 5	+20	+9
6	0	-69	-8	-43	0	0	-32	-7	-12
7	0	-115	-12	-95	0	0	-1	+12	+12
6	0	-65	-8	-36	0	0	-39	0	- 1
9	0	-1	+5	-41	0	0	-25	-2	+7
10	0	-36	-5	-48	0	0	-23	+11	+8
11	-20	-57	+13	-103	-48	-19	+17	+24	+18
12	-2	-44	-16	-69	-43	-15	-45	+2	-5
13	-10	-55	-27	-46	-81	-11	-2	-4	-5
14	-21	-45	-24	-66	-66	-14	-24	-7	+2
15	-27	-24	-15	-58	-55	-37	-3	-15	-4
16	-19	-16	-40	-103	-42	-30	-26	-2	+5
17	+3	-56	-8	-16	-41	-2	-10	-2	+6
18	-24	-70	-23	-96	-98	-7	-23	-7	-10
19	-37	-31	-4	-74	-47	-16	-3	+12	+3
20	-4	-28	-10	-8	-41	-23	-6	+7	+6
AVERAGE	-16	-49	-10	-62	-56	-17	-13	+3	+3
STAND DEVIA.	±13	±27	±14	±30	±19	±10	±17	±10	±8

TABLE 23. THE MEAN CHANGE IN REACH DISTANCES FOR NUDE VS. SUITED SUBJECTS FOR THREE HAZMAT ENSEMBLES.

REACH	CHALLENGE MEAN CHANGE FROM CONTROL VALUE (INCH)	CHALLENGE %	TRELLECHEM MEAN CHANGE FROM CONTROL VALUE (INCH)	TRELLECHEM %	MSA MEAN CHANGE FROM CONTROL VALUE (INCH)	MSA %
1 ARM UP	-2.3	-2.7	-1.9	-2.2	-7.6	-8.7
2 ARMS UP	-4.3	-5.0	-2.2	-2.5	-9.3	-10.8
FORWARD REACH*- 1 ARM	+11.3	+35.3	+12.9	+40.2	+12.2	+38.1

*TECHNICALLY THE WALL-TO GRIP DISTANCE INCREASE DUE TO THE GARMENT-SCBA

TABLE 24. THE MEAN CHANGE IN MOTION FOR NUDE VS. SUITED SUBJECTS FOR THREE HAZMAT ENSEMBLES.

REACH	CHALLENGE MEAN CHANGE FROM CONTROL VALUE (INCH)	CHALLENGE %	TRELLECHEM MEAN CHANGE FROM CONTROL VALUE (INCH)	TRELLECHEM %	MSA MEAN CHANGE FROM CONTROL VALUE (INCH)	MSA %
ELBOW FLEXION	-2.0	-3.0	-6.3	-9.7	-6.3	-9.7
SHOULDER FLEXION	-7.1	-9.7	-9.1	-12.9	-19.3	-26.2
SHOULDER/ARM EXTENSION	-8.3	-24.7	-1.6	-1.3	-3.9	-11.7
ARM ABDUCTION	-7.1	-21.9	-13.0	-18.6	-24.4	-36.4
RIGHT KNEE LIFT	-16.9	-40.9	-13.4	-13.4	-22.0	-22.0
KNEE BEND	-7.9	-24.8	-1.6	-3.8	-6.7	-22.5
TORSO FORWARD FLEXION	-10.2	-23.7	-4.3	-15.5	-5.1	-14.7
TORSO FLEXION TO RIGHT	+0.4	+4.3	+1.6	+17.0	+1.2	+12.8
TORSO FLEXION TO LEFT&	+0.4	+4.1	+0.8	+8.2	+1.2	+12.3

TABLE 25. MEANS AND STANDARD DEVIATIONS FOR THE ANTHROPOMETRY OF FIRE FIGHTER TEST SAMPLE AND THREE COMPARABLE MALE POPULATIONS

	FIREFIGHTERS		MINERS		AIR TRAFFIC CONTROLLERS		AIR FORCE FLYERS	
	X	S.D	X	S.D.	X	S.D.	X	S.D.
AGE (N=17)	30.8	4.0	32.1	9.2	28.4	6.2	30.0	6.3
WEIGHT	194.6	33.8	177.2	26.8	161.9	22.1	173.5	21.4
HEIGHT STANDING	180.5	7.8	173.7	6.8	176.8	6.2	177.3	6.2
EYE HEIGHT	82.2	2.8	--	--	81.7	3.2	81.0	3.0
ACROMIAL HEIGHT	148.2	8.6	141.9	6.0	147.0	5.8	145.2	5.8
SUPRASTERNALE HEIGHT	147.9	7.6	--	--	143.9	5.5	145.2	5.5
CERVICALE HEIGHT	153.1	7.7	149.7	6.2	150.3	5.8	152.1	5.8
CHEST HEIGHT	131.8	7.5	--	--	128.1	5.2	129.2	5.2
WAIST	107.9	5.7	103.8	5.4	106.0	5.0	106.5	4.7
BUTTOCK HEIGHT	91.5	4.9	--	--	--	--	90.1	4.4
CROTCH HEIGHT	83.9	4.4	--	--	--	--	85.1	4.2
MID-PATELLA HEIGHT	50.2	2.8	--	--	--	--	49.7	2.5
HEAD HEIGHT	22.2	1.3	--	--	--	--	22.8	1.0
BIDELTOID BREADTH	50.4	3.9	47.9	2.9	46.9	2.7	48.2	2.6
INTERSCYE	39.9	3.0	41.0	3.2	--	--	38.8	3.8
HIP BREADTH	35.9	2.5	--	--	34.7	1.9	35.3	1.9
HAND LENGTH	19.4	1.2	19.0	0.9	--	--	19.1	0.8
HEAD CIRC.	57.4	2.0	56.9	1.7	57.9	1.6	57.5	1.4
SHOULDER CIRC.	119.4	7.0	118.7	7.0	117.4	6.7	117.7	5.8
BICEPS CIRC.	33.2	4.0	34.5	2.7	30.0	2.7	32.7	2.3
FOREARM CIRC.	31.0	1.8	--	--	27.5	1.8	28.2	1.5
SCYE CIRC.	48.3	2.8	--	--	--	--	48.4	2.8
CHEST CIRC.(NIPPLE)	101.1	8.7	100.3	7.9	97.0	6.5	98.6	6.4
WAIST CIRC.(NAVEL)	93.0	10.3	91.2	10.4	--	--	87.6	7.4
HIP CIRC. (MAX BUTT)	102.7	7.9	98.2	7.2	96.8	6.0	98.6	5.5
UPPER THIGH CIRC.	59.5	5.7	56.4	4.8	--	--	58.8	4.4
CALF MAX CIRC.	39.1	2.7	37.2	2.9	36.7	2.4	37.2	2.3
SLEEVE LENGTH	88.4	5.4	--	--	--	--	90.8	3.5
SITTING HEIGHT	94.7	3.1	91.5	3.5	92.0	3.3	93.2	3.2
BUTTOCK-KNEE LENGTH	68.6	11.3	60.1	2.9	60.3	2.8	60.4	2.7

Therefore, more heat can be conducted through the clothing system. Also, wind affects the thickness of the boundary layer of air surrounding the clothing and the greater the air speed, the thinner the boundary layer which permits more heat transfer into the clothing.

PHYSIOLOGICAL FACTORS

Heart Rates: Figures 1A and 1B clearly show the effect of the outside environmental temperatures on heart rates. In the hot/dry and hot/wet tests, the final absolute heart rates were 155 to 175 beats/min regardless of the type of ensemble worn. These elevated heart rates are typically seen in physically fit individuals involved in medium to heavy work (Barnard, 1975; Duncan et al, 1979). The metabolic rate associated with this level of work is 5.5 to 6.5 (METS) times resting levels (Erb, 1961). Davis and Dotson (1976), however, have reported that the physical activity in simulated fire fighting environments required 97% of VO_2 (12 METS).

In general, there is little difference in heart rates while wearing the various suits. Any differences tend to be cancelled out by the large standard deviations. Resultant final heart rates from the comfort or cold conditions were similar and much lower (95 to 127 beats/min) than those measured during the hot/dry or hot/wet exposures. In the comfort tests, there are significant differences between the Trellechem and Challenge ensembles but these suit differences disappear in the cold tests. The effect of dragging a 250 ft. tether line is readily apparent in a 35 beats/min differential in the heart rates. The single level B exposure in the hot/dry environment Shows a significant reduction in heart rate (146 vs. 156 to 165 beats/min).

In Figure 1B, individual and diurnal variations are negated, as only the changes in heart rate are plotted. Again, little differences in heart rates between clothing worn are seen in both hot exposures and these small differences can be attributed to age and physical fittness effects. The heart rate response during the cold exposures are the result of the work load and overcoming the emcumberance of the clothing ensembles. The difference in heart rates seen in Figure 1A between the level A and level B clothing in the hot/dry exposures tend to be less when only heart rate changes are plotted in Figure 1B.

Body Core Temperatures: The rectal or core temperature of the body is one of the most meaningful physiological parameters reflecting strain on the body in a work/temperature environment. In Figures 2A and 2B, the final rectal temperatures show the combined effect of temperature and work in final core temperatures. Individual absolute T_R levels in the hot/dry and hot/wet conditions did reach or exceed 102.0°F The results plotted in Figure 2A show little difference between the clothing worn and $T_{R.}$ In Figure 2B the only dissimilar T_R was during the hot/wet exposure white wearing the Challange suit. This result can be explained by the average lower WBGT temperature experienced during the Challenge exposures (Table 14). Again, a significant difference is seen between the tethered or untethered STAS suit. But, the dry bulb and WBGT's were different so the change in T_R would be less if the environmental variables were comparable to those during the other suit exposures. The body temperature changes seen during the cold conditions indicates the effect of the work bad. These data suggest less work is associated with wearing the Trellechem suit as opposed to the MSA suit.

Although all subjects completed the entire test protocol, one subject at the end of the test period exposed to hot/wet conditions, was unable to continue waking to the dressing room. Also, during the hot/dry tests, two subjects were barely able physically to complete the test protocol. Therefore the test monitors felt that these hot/dry or wet test conditions approached the tolerance limits of the fire fighters. According to NIOSH criteria, the hot/dry WBGT of 33.9°C exceeded the permissable exposure for work in hot environments (Unknown author, 1966). The WBGT of 29.3°C during the hot/wet tests was marginal at best. Goldman (1973) has suggested the following significant WBGT levels based on physiologic studies for the U.S. Army: 81°F-threshold of concern, 84°F curtailment of strenuous exercise for unseasoned persons, 88°F-curtailment of all strenuous exercise and 88°-90°F if absolutely necessary, heat acclimated persons can work for up to 6 hours. These suggested limits must be lowered 5.4°-9.0°F or more for persons wearing impermeable clothing.

An overshoot of rectal temperature occurs even when the person is undressed as rapidly as possible and seated at rest in an air conditioned or cool environment. Rectal temperatures were measured 30 mbs after the end of each test and in most cases had lowered only 0.5°F from the end of test levels (Fig. 2C). This cooling increment represents approximately a 25% reduction toward control values. Therefore, a person should be closely monitored after HAZMAT incidents in hot/dry or hot/wet environments to prevent possible heat collapse. This possibility would become greater if the same fire fighter rested for thirty minutes, then resuited and returned to work in that hot environment.

Sweat Loss: Loss of body water has a profound effect not only in heat regulation but also on the circulatory system. Fire fighters working in the heat undergo simultaneous changes in these regulatory systems. Work results in. the depletion of muscle oxygen stores required to support muscular contraction so the heart and respiratory rates increase to provide more oxygen to these working muscles. To meet the VO_2 demand, various blood pools such as sequestered in the abdominal area are shunted to meet the demand for increased blood supply to these muscles. At the same time, muscular work provides heat. In order to dissipate this metabolic heat, the peripheral blood vessels dilate which in turn requires more blood volume to the skin's surface. If in addition, the fire fighter is working in a hot environment, surface blood vessels may dilate further and the sweating mechanisms brought into play to provide evaporative cooling of the skin's surface. Therefore, dehydration and its consequent reduction in blood plasma volume increases the circulatory strain on a person and reduces the tolerance of a fire fighter to a heat stress. Adolph (1946) and Pitts et al. (1944) found that a 1 to 2% body dehydration caused an an increase in circulatory strain resulting in an increase in HR and TR of men working in the heat. Adolph has called this effect "dehydration exhaustion" which he considers a form of heat exhaustion. Figure 4 traces the volunteer hydration status of the fire fighters over the three day test period. As shown in Table 16, some fire fighters replenished their water losses adequately while others did not. It might be wise for fire fighters to check their body weight daily to ensure proper hydration status during the hot months. Even during the cold exposures, 0.5 Ibs of sweat was lost which over the period of three days amounted to 2.0 tbs. Gatorade and/or water was given to all subjects upon completion of each test to replenish the water and mineral toss as rapidly as possible. Even with this regimen, three fire fighters showed an overall water deficit at the end of the hot/dry tests (Table 16). Because of the severity of the hot/dry conditions, some subjects complained of nausea or dizziness toward the end of the test cycle.

Under comfort conditions, wearing the TREL suit resulted in the least body water loss and increase in HR ant TR. The increase in these parameters while wearing other protective ensembles above that of TREL reflect to some degree the effort required in working against the, clothing or the design deterrent of the clothing. Simply put, clothing design affects the ease of mobility and therefore the effort involved in performing work in the ensembles. In terms of work load, it was described as moderate by the fire fighters and this is supported by Erb's

(1981) study. In this study, moderate work is defined as varying from 5.0 to 7.5 Kcal/min (4.2 to 8.4 METS) or equivalent to lifting 50 Ibs maximum or with frequent lifting and carrying objects of 25 Ibs. In another study, Webb et al (1964) measured the energy expenditure of a fire fighter carrying 50 lbs of hose 500 ft. as 227 Kcal/hr.

Maximal sweat losses for hot/dry and hot/wet tests were 5.3 and 2.6 lbs respectively. These weight losses are very high considering the short work times although Kuno,(1956) has reported higher levels of 8.8 Ibs sweat loss during very stressful work in the heat. Rectal temperatures rose rapidly and were 1.8°F over resting levels. The maximum individual values recorded at the end of the hot/dry test was 101.3°F and 102.2°F for the hot/wet tests. Since most of the fire fighters' body is covered by a moisture impervious shell, the physiologic responses of the one person wearing a level B protective garment (SIJAL) were similar to that whilewearing level A clothing.

Respiration Rate and Blood Pressure: Tables 8 and 9 list the average Changes in these physiologic parameters while wearing the various ensembles. The changes in these variables are essentially the same for all clothing ensembles considering the high standard deviations and the higher values simply reflects the level of work effort. The SCBA pressure drops (Table 15) reflect the oxygen demand and are essentially the same across clothing and climatic conditions.

CLOTHING

Moisture in Clothing: Figure 6 shows the amount of moisture measured in the clothing during testing worn under the HAZMAT protective ensembles. As one might expect, the most sweat was retained in the T-shirt and station pant during all climatic tests. The largest amount of retained moisture was measured during the hot/dry exposures where water was poured out of the boots after the test. These finding points out the importance of considering the water absorptivity of these clothing items before purchase. Synthetic materials absorb very little water. Also in back to back HAZMAT work boots, dry undergarment should be available to replace the wet clothing during the "rehab" period.

Clothing Temperatures: Tables 13 shows the temperatures recorded inside the HAZMAT clothing shell measured over and under the face shield. The tabular data are the average for these two measurements. These measured values result from globe as well as ambient temperatures.

Therefore, in the hot/dry or hot/wet exposures, inside suit temperatures exceeded ambient temperatures during many tests. Working in the shade could reduce this environmental thermal load considerably as would cooling the suit by hosing it down with water.

DESIGN CONSIDERATIONS

Anthropology: In order to determine the body size characteristics of this sample, each subject was measured for a series of 29 traditional and functional anthropometric dimensions. The measurement procedures have been described previously (Annis et al, 1987; and Veghte, 1985). Subjects were measured while dressed in shorts and T-shirts. The individual data are in Appendix A. The means and standard deviation for each measurement were calculated for the 17 subjects for which complete data were collected. These data are presented in Table 25 along with equivalent measurements obtained from three comparable male populations (Churchill et al, 1977; Snow and Snyder, 1965). In general these fire fighter test samples were just slightly larger than the comparative populations. Data for the selected dimensions are unavailable from a larger fire fighter sample, however, the height and weight of 100 fire fighters in the Washington, DC area was reported by Dotson et al, (1976?) and averaged 70.0 ins and 183.9 Ibs respectively. Respondents (n-107) to a questionnaire conducted in conjunction with Task 1 of this study showed an average height of fire fighters to be 71.0 in and the average weight of 186.8 Ibs. Since the correlation of linear dimensions with height and the volume/mass related dimensions with weight are good, it is fair to conclude that our test sample was probably representative of the fire fighter (male) population in general.

Reach and Body Motion in HAZMAT Clothing: Body flexibility is critical to the ability of fire fighters to perform effectively. In order to examine the effect of the three test ensembles on body mobility, a series of functional reach and simple/complex joint measurements were measured on the test subjects (Veghte, 1965). Fire fighters were first tested in shorts and t-shirt to establish “nude” (control) baseline values for each maneuver. The nine movements associated with joint range of motions were measured (in degrees) using a gravity actuated protractor device called the Leighton flexometer (Leighton, 1955), and the three reaches were measured with an anthropometer. The suited measurements were performed while the subjects were wearing an SCBA and the garments were inflated. On the figures and tables which follow, the data for both types of tests have been quoted in terms of the nude/control versus clothed differences for each ensemble and for each subject individually or the mean difference observed for the full test sample. As with all tests of the type performed, the variation between subjects and between the various tests is quite large. The mean values obtained, however, represent a reasonable approximation of the effects observed.

The nude and clothed differences in reach distance for each subject wearing the three different ensembles are presented in Tables 17 through Table 25. The mean differences for the subjects are given at the bottom of these tables and plotted on Figures 7 and 8. Tables 23 and 24 provide the summary data for all three ensembles. The reduction in overhead reach ranged from 2.2% to 8.7% for the one-hand reach and from 2.5% to 10.8% for the two hand reach. In both tests the Challenge showed slightly larger reductions than Trellechem, but significantly less than the MSA ensemble. The ability to abduct the arms in the MSA ensemble was greatly affected by the SCBA design in the shoulder area. The forward reach (1 arm) measurements are in error since the values reflect the large increase (about 11 to 13 in.) in the wall-togrip distance due to added depth of the garment-SCBA combination. The values therefore may be interpretated to represent the fore-aft workspace requirement when such ensembles are worn. The 35 to 40% increase in the distance indicates the difficulty one may have working in HAZMAT ensembles in tight work areas.

The ability to perform in bulky and inflated ensembles is obviously influenced by restrictions on body flexibility. Not only are “simple" tasks made more diffIcult or impossible, but also the energy cost of work in general increased proportionally, Biomechanically, work space is increased while increased metabolic heat must be dumped or heat stress may also occur. The nine tests of body mobility attempt to isolate how the garment effects areas or specific joints during specific movement. The suited minus the nude control values for each subject are presented for the Challenge, Trellechem, and MSA ensembles on Tables 23 and 24 respectively. These data are summarized on Table 25 and plotted in Figures 7 and 8. In general, the Challenge tended to show some what less reduction in arm-shoulder movement than the other garments. The Trellechem showed lessened loss of motion in those movements that involved multiple joint systems whereas the MSA ensemble particularly demonstrated large loss of movement in the shoulder and knee related motions. In all cases the loss in motion may be accredited to the inflation effects, fabric pull or physical obstruction due to garment bulk or SCBA parts as opposing body surfaces are brought into proximity with movement. Although we were not able to demonstrate a clean relationship between the body size of our subjects and the mobility measures in the the three ensembles, clearly multiple Sizing of HAZMAT suits should be considered as a means to improve overall ability to perform more complex maneuvers. The basic anthropometric dimensions are compared to data bases from various other groups and tabulated in Table 25. Most body dimensions are similar across groups although the fire fighters were heavier and taller.

Fire Fighter's Comments The following subjective comments are representative of those reported on the test questionnaires after each test.

Challenge: The major problem with this ensemble was the “ballooning” of the suit. This overinflation restricted movement of the arms, waist flexion and downward vision. When subjects were working on the barrel or picking up the pails, they had to do a deep knee bend to expel the air from the suit in order to bend over sufficiently. Also, the design of the sleeves tended to push up on the upper arm when inflated so that carrying the pails was uncomfortable and difficult for some subjects. The suit pressure also tends to push the gloves off of the hands. A reduced valve “cracking” pressure is a simple remedy. The visor visibility was limited for short persons. At times, the breathing tube snagged on the suit on an obstruction just below the face piece. The inside color of the CHAL suit was light which was psychologically beneficial as it was perceived by the subjects as conducting “less heat” than the suits with darker interiors. The rubber overglove was ripped while securing the overpack drum. One fire fighter complained that the socks tended to slide on the slippery teflon surface of the bootee.

MSA: The hood design Is poor and pushes down on the inner face mask forcing the fife fighters to keep pushing the hood up from the outside to maintain adequate vision and to avoid the uncomfortable pressure On the head and neck. The back Of the hood presses against the nape of the neck which was uncomfortable when hot. The visibility is poor as the face piece “rides” too low. Upward vision is particularly bad. The hard plastic ring on the top of the boot rubs against the shin causing blisters and making walking uncomfortable. The Dolman sleeve construction severly limited overhead arm movement. Poor boot fit resulted in blisters on the feet. The rubber gloves were tom in several cases while working on the overpack drum. The fire fighters complained of “hot” feet, poor boot fit and suit too hot and heavy.

Trellechem: The hood design is poor and when looking down while working on the barrel the suit rests on the nape of the neck causing uncomfortable pressure. The hands could not be withdrawn from the gloves to reach the SCBA controls because of the inner wrist seal. This problem is considered a major design deficiency by the fire fighters as the likelihood of a SCBA failure is far greater than the need for a secondary chemical barrier at the wrist. The downward visibility was poor and the fire fighters were constantly pushing up on the visor to see. The zipper arrangement was poor and a person couldn’t get out of the suit without assistance. The boots fit poorly and rubbed on the shins. Other complaints included poor peripheral vision and the crotch was too low.

Sijal: The straps for the inner face mask became extremely hot and uncomfortable as the test progressed. To remedy this problem, a cap or head cover should be worn over the hood.

General Comments: The gloves on all suits were ruptured repeatedlty while the fire fighters were handling the tools and loosening or tightening the protective ring on the overpack barrel. Overgloves must be worn to prevent the suit gloves from rupturing. Rough sizing of the protective ensemble could avoid some of the visibility or hood problem. A simple helmet/suit front pull down strap would also enhance visibility for a wide height range of fire fighters.
Visor fogging was a serious problem at all of the test sites and was particularly severe in the hot/wet tests. In two of these tests, the fogging was so severe that the fire fighter could not see and the test monitor had to lead the fire fighter by the hand in order to complete the work schedule. It was suggested by Memphis fire fighters to apply a thin film of Prell shampoo on the inside of the HAZMAT suit visor and inner face piece which dramatically reduced the visor fogging.

TABLE 26. RANK ORDER OF ENSEMBLES

ENSEMBLE SELECTION CRITERIA		TRELLECHEM	CHALLENGE	MSA	WEIGHTED PRIORITY %
SUBJECTIVE EVALUATION		1 (0.40)	2 (0.80)	3 (1.20)	0.40
ANTHROPOMETRIC MOTION		1 (0.15)	3 (0.45)	2 (0.30)	0.15
HYSIOLOGICAL VALUATION	CHANGE H R	1 (0.15)	2 (0.30)	3 (0.45)	0.15
	CHANGE TR	1 (0.15)	2 (0.30)	3 (0.45)	0.15
	CHANGE NUDE	1 (0.15)	2 (0.30)	2 (0.30)	0.15
RAW TOTAL	NUMERICAL TOTAL	5 (1.00)	1 1 (2.15)	1 3 (2.70)	
	RANK ORDER	1 (1)	2 (2)	3 (3)	

Table 26 is a summation of rank ordering the pertinent variables that can be used as a guide for assessing the various ensembles. The weighed priorities have been arbitrarily selected based on experience and judgment. This evaluation is only as valid as are the level of the weighed priorities but at least it provides a framework for arriving at a logical evaluation. The fire fighters' ensemble preference was in favor of the TREL Ensemble with the CHAL second. Physiologically, the rank order is TREL first, CHAL second and MSA third.

RECOMMENDATIONS/CONCLUSIONS

1. This work bad in hot/dry or hot/wet climatic conditions imposes a serious physiologic strain on ail fire fighters.
2. Physical conditioning and heat acclimatization is very Important for HAZMAT personnel because of the level of physiological strain.
3. The rehydration status for personnel involved in HAZMAT incidents should be closely monitored in hot climates and they should not be allowed to continue fire service duties until it approaches their normal level.
4. The impact of these data on "rehab" is extremely important. For example, if a person works a HAZMAT incident in hot weather, they should not be expected to fight a structural fire on the next shift. The body core temperatures can take a long time (hours) to return to resting levels. Ideally, the fire fighter should have a full day to recover.
5. Preventive procedures such as periodic hosing off the HAZMAT suits should be considered to reduce the physiologic strain imposed by climatic conditions and metabolic generated heat bad caused by the work bad.
6. The design and sizing of the protective ensembles tested could be improved which would enhance the capability of performing necessary tasks and to reduce the "encumberance" of the clothing.

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